Low NO_x

Reducing the Thermal NOx

The earth has plentiful air; but the quality of the air depends largely on the amount of industrial wastes and other pollutants (impurities) that people add to the atmosphere. Air pollution is a serious problem in most of the world's big cities. Polluted air harms our health. It also injures plants and animals, damages building materials, and even affects the weather. Rheem is committed to reducing pollutants through our Low NOx programs.

Low NOx burners are one of several combustion technologies Rheem Manufacturing Company is using to reduce emissions of Nitrogen Oxides (NOx.). By reducing the flame temperature on the main burner, we can reduce the amount of nitrogen oxides that are created. Let me explain.

What is NOx? (pronounced like the animal ox – with an 'n' in front)

NOx represents a family of seven compounds. The Environmental Protection Agency (EPA) regulates only nitrogen dioxide (NO_2) as a surrogate for this family of compounds because it is the most prevalent, human caused form of NOx in the atmosphere. Nitrogen dioxide is not only an important air pollutant by itself, but also reacts in the atmosphere to form ozone (O_3) and acid rain. The family of NOx compounds are listed in the table below:

Formula	Name	Properties
N_2O	Nitrous oxide	Colorless gas, water soluble
NO N_2O_2	Nitric oxide Dinitrogen dioxide	Colorless gas, slightly water soluble
N_2O_3	Dinitrogen trioxide	Black solid, water soluble, decomposes in water
NO_2 N_2O_4	Nitrogen dioxide Dinitrogen tetroxide	Red-brown gas, very water soluble, decomposes in water
N_2O_5	Dinitrogen pentoxide	White solid, very water soluble, decomposes in water

Nitrogen oxides pollute the air. Pollutants are released by burning fossil fuels such as natural gas, coal, and gasoline. Automobiles and other mobile sources contribute about half of the NOx that is emitted. Electric power plant boilers produce about 40% of the NOx emissions from stationary sources. Additionally, substantial emissions are also added by other sources as industrial boilers, incinerators, gas turbines, reciprocating spark ignition and diesel engines in stationary sources, iron and steel mills, cement manufacture, glass manufacture, petroleum refineries, and nitric acid manufacture. Nitrogen oxides can also return to earth as nitric acid, a major ingredient of acid rain. Nitrogen and pollution are an unpleasant fact of life. People influence the nitrogen cycle. For instance, the use of nitrogen fertilizers adds nitrogen to the soil. Rainwater carries unused fertilizer and other nitrogen compounds into streams and lakes.

Now that we have a very simple understanding of NOx, let's look at what we need in order to burn a fuel such as natural gas. Before we can have combustion, we must have a fuel source, an air source (for oxygen) and an ignition source (to get things going).

What is air?

Air consists of a mixture of gases that extends from the earth's surface to outer space. The principal gases of the air are nitrogen and oxygen. Nitrogen makes up about 78 per cent of dry air--that is, air from which all water vapor has been removed. The water vapor in the air is water in the form of an invisible gas. Oxygen accounts for about 21 per cent of dry air. The remaining 1 per cent consists chiefly of argon, with only extremely small amounts of other gases include carbon dioxide, neon, helium, krypton, hydrogen, xenon, and ozone. For the sake of our explanation, we will use 78% nitrogen and 21% oxygen to represent the air that we breathe.

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What is combustion?

Fire is the heat and light that comes from burning substances. In 1777, Antoine Lavoisier, a French chemist, proved that burning is the result of the rapid union of oxygen with other substances. As a substance burns, energy, in the form of heat and light, are produced. The chemical reaction we call ‘burning’ is also called combustion. For example, when oxygen unites with natural gas in the presence of an ignition source, the reaction takes place rapidly -- and heat and light are given off. This process may be described by any of the two words: burning or combustion.

Combustion is a chemical reaction that gives off heat and light. In most cases, combustion involves the rapid combination of oxygen with a fuel to produce flame. The fuel may be a solid, liquid, or gas. In our water heaters, it is either natural or propane gas.

Three conditions must exist before combustion can take place. There must be a fuel or a substance that will burn (such as natural gas). The fuel must be heated to its ignition temperature with a standing pilot or spark. The ignition temperature is the lowest temperature at which combustion can begin and continue. Finally, there must be a sufficient amount of oxygen, which usually comes from the surrounding air. In our case, combustion occurs between a gaseous fuel and the oxygen in the air. The heat causes the molecules of oxygen and nitrogen to bond forming the substance we commonly refer to as NOx.

For natural gas, or methane (CH_4), to burn, two molecules of oxygen are needed for each molecule of methane. When heat is applied, we have combustion. If the mixture has the perfect two molecules of oxygen and one molecule of methane -- $O_2 + O_2 + CH_4$ -- then we have perfect combustion. The products of perfect combustion are carbon dioxide and water vapor. The basic model of the combustion process is important because: 1) It demonstrates that only carbon dioxide and water vapor result if a fuel gas is completely burned; 2) It shows the exact amount of oxygen needed to burn a specific amount of fuel; 3) There are definitive amounts of known products when completely burning a fuel gas.

By extrapolating this formula, one cubic foot of methane needs two cubic feet of oxygen to completely burn. The problem is that a normal atmosphere – or air – is not pure oxygen. It is the imperfect combustion of gas fuels that cause pollutants and contaminants.

What does imperfect combustion produce?

An entire piece of wood or coal will not burn, even if there is sufficient oxygen present. Most of us have taken the ashes from a charcoal grill or fireplace. The ash, generally a mixture of minerals, is present in the fuel, but will not unite with the oxygen. Some fuels have a lower ash content than others. This is important to remember when buying charcoal or wood because you want the fuel with the lowest ash content.

When we design a burner system for a water heater, the same holds true. We want as little post-combustion content as possible. Substances that burn in air are nearly always composed of two elements, carbon and hydrogen, or their compounds. For example, natural gas, gasoline, and fuel oils consist of many compounds of hydrogen and carbon. When these fuels burn, the oxygen of the air unites with the carbon and hydrogen to form carbon dioxide gas and water vapor. These usually mix with the air and disappear. The uniting of the oxygen with the hydrogen and the carbon is what produces the heat and flame of the fire.

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Remember, air is approximately four parts (78%) nitrogen and one part (21%) oxygen. When the fuel gas combines with the oxygen in the air to burn at the main burner, the nitrogen is still present. It is the heat, part of the chemical process of combustion, that unites nitrogen and oxygen atoms to form what we commonly refer to as NOx. NOx is formed in varying degrees based on the temperature of heat in the burner flame and the exact percentage of oxygen and nitrogen in the air during combustion. The hotter the flame, the more NOx than can be formed; the cooler the flame, the less NOx that can be formed.

We reduce the formation of NOx in a water heater by controlling the temperature of the flame at the main burner and controlling the amount of oxygen and nitrogen available for the reaction. A hotter flame has the potential of producing more NOx products; whereas, a cooler flame inhibits the formation of NOx products. This is referred to as “reducing the thermal NOx”. The concentration of thermal NOx is restricted by controlling the temperature of combustion. Combustion temperatures that are cooler do not allow the nitrogen and oxygen molecules to bond and form a NOx compound.

Conclusions

Engineering research and product development will continue to search for more operational answers and try to balance them against cost and efficiency. Costs will decrease as technology advances, operating experience is gained, and better designs become available. We can expect the level of pollution prevention and control technology effectiveness will improve with time.

Other Low NOx references:

Federal government technical bulletin dated November 1999 and entitled “Nitrogen Oxides (NOx), Why and How They Are Controlled” available at http://www.epa.gov/ttn/catc/dir1/fnoxdoc.pdf.